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14. ABSTRACT
A comprehensive study integrating surface observations, data from in-situ measurements, and a nested numerical model with two related topics was conducted in this project. the WRF PBL schemes are very much sensitive to complex terrain regions. No single parameterization can represent all events (i.e., weather conditions) and all mountainous terrain regions (e.g., Sierra-Nevada). The use of high-resolution (i.e., grid spacing at 4 km or less) modeling is essential to advance our understanding of mountain-valley flows in association with stable boundary

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Report Title

Final Report: Quantifying the Stable Boundary Layer Structure and Evolution during T-REX 2006

ABSTRACT

A comprehensive study integrating surface observations, data from in-situ measurements, and a nested numerical model with two related topics was conducted in this project. the WRF PBL schemes are very much sensitive to complex terrain regions. No single parameterization can represent all events (i.e., weather conditions) and all mountainous terrain regions (e.g., Sierra-Nevada). The use of high-resolution (i.e., grid spacing at 4 km or less) modeling is essential to advance our understanding of mountain-valley flows in association with stable boundary layer conditions. Observations and model results suggest that the T-REX/EOP4 event never quite achieves a truly steady-state down-valley flow condition near the surface, as fluctuations in the jet strength and the near surface mean valley wind direction appeared to occur throughout the event. The simulation results also suggest that adding two additional nests: an outer 13.5 km and an inner 500 m can produce a much better evolution of the nocturnal low-level jet and especially in terms of the speed max. It also appears as if the addition of the outer 13.5 km nest was far more critical then the addition of the inner 500 m nest, lending support to the idea that accurately capturing the synoptic condition was a critical player in this valley low-level jet event. Overall, the low-level nocturnal down-valley jet is fairly well resolved by the simulations in terms of timing, spatial location, and height above the valley floor.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/08/2013	6.00	Kim Whitehall, Sen Chiao, Margarette Mayers-Als. Numerical Investigations of Convective Initiation in Barbados, Advances in Meteorology, (07 2013): 0. doi: 10.1155/2013/630263
08/08/2013	9.00	Mark R. Jury, Sen Chiao. Leeside Boundary Layer Confluence and Afternoon Thunderstorms over Mayaguez, Puerto Rico, Journal of Applied Meteorology and Climatology, (02 2013): 0. doi: 10.1175/JAMC-D-11-087.1
08/27/2011	1.00	Sen Chiao, Stanley Czyzyk, Andre K. Pattantyus. Improving High-Resolution Model Forecasts of Downslope Winds in the Las Vegas Valley, Journal of Applied Meteorology and Climatology, (06 2011): 1324. doi: 10.1175/2011JAMC2586.1
09/29/2014	10.00	Mark R. Jury, Sen Chiao. Representation of Ethiopian Wet Spells in Global and Nested Models, Advances in Meteorology, (03 2014): 0. doi: 10.1155/2014/237374
09/29/2014	11.00	Sen Chiao, Robert Dumais. A down-valley low-level jet event during T-REX 2006, Meteorology and Atmospheric Physics, (09 2013): 0. doi: 10.1007/s00703-013-0279-z

TOTAL: **5**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Eiserloh, A. J, and S. Chiao, 2014: Modeling Studies of Landfalling Atmospheric Rivers and Orographic Precipitation over Northern California, 94th AMS Annual Meeting, Atlanta, GA, Feb 2-6, 2014.

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received		Paper
08/27/2011	2.00	Andre Pattantyus, Sen Chiao, Stanley Czyzyk. IMPROVING DOWNSLOPE WIND FORECASTS IN A MOUNTAINOUS REGION: ASSESSING UNCERTAINTY IN HIGH-RESOLUTION MODELING OVER THE LAS VEGAS FORECAST ZONE, 24th Conference on Weather and Forecasting/20th Conference on Numerical Weather Prediction. 26-JAN-11, . : ,
08/27/2011	3.00	Travis Washington, Sen Chiao. Numerical Studies of Lower Boundary Forcing on Tropical Storm Fay (2008) over Southern Florida, 23rd Conference on Climate Variability and Change. 26-JAN-11, . : ,

TOTAL: **2**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u> <u>Paper</u>

08/08/2013 7.00 Yasuhara, Scott , Forgeron, Jeff , Rella, Chris , Franz, Patrick , Jacobson, Gloria , Chiao, Sen, Saad, Nabil. Measurements of Carbon Dioxide, Methane, and Other Related Tracers at High Spatial and Temporal Resolution in an Urban Environment,
EGU General Assembly 2013. 12-APR-13, . : ,

TOTAL: **1**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

<u>Received</u> <u>Paper</u>

08/08/2013 8.00 Sen Chiao, Robert Dumais, Jr.. A Down-Valley Low-Level Jet Event During T-REX 2006,
Meteorology and Atmospheric Physics (04 2013)

08/28/2011 4.00 Sen Chiao, Robert Dumais, Jr.. Investigations of a Down-Valley Flow Event During T-REX 2006,
Weather and Forecasting (05 2011)

09/30/2014 12.00 Arthur Eiserloh, Sen Chiao. Modeling studies of landfalling atmospheric rivers and orographic precipitation over northern California,
Meteorology and Atmospheric Physics (03 2014)

TOTAL: **3**

Number of Manuscripts:

Books

<u>Received</u> <u>Book</u>

TOTAL:

Received   Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT SUPPORTED	Discipline
Arthur Eiserloh	1.00	
Angela Reside	0.50	
FTE Equivalent:	**1.50**	
Total Number:	**2**	

Names of Post Doctorates

NAME	PERCENT SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT SUPPORTED	National Academy Member
Sen Chiao	0.08	
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT SUPPORTED	Discipline
Jeff Forgeron	0.00	Meteorology
Jane Taifane	0.00	Meteorology
FTE Equivalent:	**0.00**	
Total Number:	**2**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 2.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 3.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 2.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Arthur Eiserloh
Travis Washington
Andre Pattantyus
Total Number: 3

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachment

Technology Transfer

The PI has been collaborating with experts in quiescence boundary layer modeling including Mr. Robert Dumais at the US Army Research Laboratory as well as Mr. Stanley Czyzyk at the National Weather Service Forecast Office (NWSFO) in Las Vegas. The PI has regular emails/teleconferences and seminars to ARL and NWS. The new configuration of the Weather Forecasting and Research model for complex terrain has been transferred to the NWSFO in Las Vegas.

Final Report
Proposal Number: 54155-EV
Quantifying the Stable Boundary Layer Structure and Evolution during T-REX 2006
Principle Investigator: Sen Chiao, Florida Institute of Technology and San Jose State University

1. Statement of the problem studied

A comprehensive study integrating surface observations, data from in-situ measurements, and a nested numerical model with two related topics was proposed in this project:

(1) Turbulent Closure: To evaluate the two primary PBL parameterizations (Mellor-Yamada-Janjic scheme (MYJ) and Yonsei University scheme (YSU)) as well as quantify differences at a fine scale model output using the different turbulent mixing/diffusion options in the WRF-ARW model; and

(2) Terrain Influences: To investigate the terrain slope effects upon the horizontal and vertical eddy viscosity coefficients calculation. The different terrain averaging and filtering/smoothing schemes will be examined in order to quantify their impact on SBL forecast results.

The working hypotheses were: (1) the average error (bias) of modeled sensible heat flux at 10 meters is within 10% of the measured flux at 90% confidence level; and (2) the choice of sub-grid terrain representation is not significant in the error of averaged winds at some height during stable conditions.

2. Summary of the most important results

The use of high-resolution (i.e., grid spacing at 4 km or less) modeling is essential to advance our understanding of mountain-valley flows in association with stable boundary layer conditions. Observations and model results suggest that the T-REX/EOP4 event never quite achieves a truly steady-state down-valley flow condition near the surface, as fluctuations in the jet strength and the near surface mean valley wind direction appeared to occur throughout the event. More specifically, surface winds with a distinct and persistent westerly component were seen throughout the night and early morning over much of the valley floor. The simulation results also suggest that adding two additional nests: an outer 13.5 km and an inner 500 m can produce a much better evolution of the nocturnal low-level jet and especially in terms of the speed max. It also appears as if the addition of the outer 13.5 km nest was far more critical then the addition of the inner 500 m nest, lending support to the idea that accurately capturing the synoptic condition was a critical player in this valley low-level jet event. Overall, the low-level nocturnal down-valley jet is fairly well resolved by the simulations in terms of timing, spatial location, and height above the valley floor (Chiao and Dumais 2013).

In T-REX EOP4 simulations, the temperature profiles indicated a conditionally stable environment which became more stable as the surface cold pool formed. Estimates of the depth of the cold pool are about 100 m. The effects of this on mixing within the boundary layer can be seen in the vertical velocity fields. Stronger vertical motions are found near the valley slopes and above the temperature inversion. The motions near the slopes are associated with the nocturnal downslope flows, while the upper level motions are associated with detrainment from the vertical wind sheer and mixing at the top of boundary layer. The layered flow structure also follows the vertical velocities pattern. Slope flows dominate the surface layer, with a transition to valley flow above this in the residual layer. Exchange between the layers is implied by the variation of

vertical velocities. Moisture appeared to be entrained from the surface layer to the residual layer. The externally forced flow layer (southerly flow near 3000 m) also shows large vertical velocities in the boundary with the valley flow but these do not persist as the external flow grows in strength. Further analysis of virtual potential temperature profiles as well as flux tower data would reveal the extent of mixing and exchange between layers.

The model vertical resolution is limited by the complicity of terrain within Owens Valley. The lowest vertical level is at a height of 102 m above the ground, which meant that all surface flows are not explicitly solved but resulted from similarity theory in the boundary layer scheme. Overall, there is good agreement between observations and the model for stations across the valley throughout the event. Nevertheless, there is no relation for surface air temperature in QNSE scheme similarity theory making it challenging to forecast this variable given model results (Pattantyus et al. 2010a, b; Chiao and Dumais 2013).

In addition to the stable boundary layer research, the PI and a graduate student (Travis Washington) were examining the sensitivity of planetary boundary layer schemes in association with landfalling hurricanes (e.g., Tropical Storm Fay 2008). The goal was to advance our understanding of how lower boundary forcing affects hurricane intensity before, during and after landfall (Washington and Chiao 2013). Also, the PI and a graduate student (Kim Whitehall) were investigating the island scale convective initiation and its sensitivity with boundary layer parameterization over maritime environment. The target areas include Barbados and Puerto Rico (Whitehall et al 2013).

The comparisons of the WRF model planetary boundary layer schemes were also conducted to study a downslope windstorm and rotors in Las Vegas valley. Two events (March 20, 2011 and April 27, 2010) occurred near the Owens Valley, CA have been investigated. It was one of the objectives that the high-resolution model results can be evaluated using GOES-R baseline products such as the Downslope Mountain Wave Turbulence (Reside and Chiao 2013). Using Doppler lidar measurements, a cold front event over the Bay area is also under investigation. The goal is to better evaluate the WRF model physics (i.e., planetary boundary layer schemes) under urban scale condition. Using lidar data, a detailed boundary layer evolution was able to record (Flaiz et al. 2012). In addition to those research activities listed above, two modified PBL schemes based on YSU and MYJ with k-epsilon closure assumption are developed. Simulations with these two new schemes are ongoing. Results will be compared with data collected from MATERHORN field experiment.

Overall, the WRF PBL schemes are very much sensitive to complex terrain regions. No single parameterization can represent all events (i.e., weather conditions) and all mountainous terrain regions (e.g., Sierra-Nevada). The comparisons performed for terrain center around a conventional averaging method that tends to reduce mean barrier heights and fill-in valleys, and a reflective envelope topography method that essentially results in much steeper model terrain. Results from this project suggest that the reflective envelope method when used with the Quasi-Normal Scale Elimination (QNSE) and Mellor Yamada Janjic (MYJ) schemes reproduce the surface flow the best in the Owen Valley, CA, but the Yonsei University (YSU) scheme performed better in the Las Vegas Valley. The inversion height, strength, and low-level stability and wind speeds near the surface are factors to be further investigated (Pattantyus et al. 2011; Chiao and Dumais 2013)**.** Initial and time-dependent lateral boundary conditions may be further improved via data assimilation or surface obs. nudging (Eiserloh and Chiao, 2014).

3. Bibliography

Chiao, S., and R. Dumais, 2013: Investigations of a down-valley flow event during T-REX 2006, Meteorology and Atmospheric Physics, 122, 75-90. doi: 10.1007/s00703-013-0279-z.

Eiserloh, A. J, and S. Chiao, 2014: Modeling studies of landfalling atmospheric rivers and orographic precipitation over northern California, Meteorology and Atmospheric Physics, conditionally accepted.

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Pattantyus, A., and S. Chiao, 2010b: Numerical studies of convective and stable boundary layer evolution in mountainous regions. Proceedings of the International Symposium for the Advancement of Boundary Layer Remote Sensing (ISARS), Paris, France, June 28-30, 2010.

Pattantyus, A., S. Chiao, and S. Czyzyk, 2011: Improving high-resolution model forecasts of downslope winds in the Las Vegas Valley. J. Applied Meteorology and Climatology, 50, 1324-1340.

Reside, A., and S. Chiao, 2013: WRF Mircophysics Performance in Forecasting Rotor Events in Las Vegas, The 12th Annual AMS student conference, Austin, TX, Jan 6-10, 2013.

Washington, T., and S. Chiao, 2012: Modeling studies of rapid intensification of tropical cyclones using HWRF. The 30th Conference on Hurricanes and Tropical Meteorology, Ponte Vedra Beach, FL, April 15-20, 2012.

Whitehall, K., S. Chiao, M. Mayers-Als, 2013: Numerical Investigations of Convective Initiation in Barbados, Advances in Meteorology, vol. 2013, doi:10.1155/2013/630263.